(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 903 192 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
24.03.1999 Bulletin 1999/12

(51) Int Cl.6: B22D 11/12

D. 1/1

X → 7,7-10

(21) Application number: 98307619.1

(22) Date of filing: 18.09.1998

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 18.09.1997 GB 9719837
21.07.1998 GB 9815798

(71) Applicant: Kvaerner Metals Continuous Casting Limited
Sheffield S9 4EX (GB)

(72) Inventors:
- Graham, Robert
  Chesterfield, Derbyshire, S40 5JP (GB)
- Perry, Robert
  Workshop, Nottinghamshire, S80 2QN (GB)
- Hutcheon, Neil
  Workshop, Nottinghamshire, S81 OXE (GB)

(74) Representative: Pawlyn, Anthony Neil
Urquhart-Dykes & Lord,
Tower House,
Merrion Way
Leeds, West Yorkshire LS2 8PA (GB)

(54) Improvements in and relating to casting

(57) The method involves a moulding stage for forming a partially solidified strand with a molten core, the partially solidified strand passing to a roller stage on leaving the moulding stage, the method comprising, at least during a portion of a casting cycle :-

providing a first portion of the rolling stage with a reducing separation between rollers, thereby defining a volume occupied by the strand in that portion;
changing the volume of the strand between the rollers in that portion by changing the position of one or more rollers; and
providing a further portion of the rolling stage with a reducing separation between rollers.

By varying the volume of the strand between the rollers in that portion the volume of the strand can be increased therein, for instance to move the zone of soft reduction away from the moulding stage, or alternatively to lower the level of the meniscus within the solidifying strand. Alternatively, the volume of the strand between the rollers in that portion can be decreased, for instance to move the zone of soft reduction towards the moulding stage, or alternatively to increase the level of the meniscus within the moulding stage.

More accurate soft reduction and less wastage material during close down of a casting run result from the application of the invention.

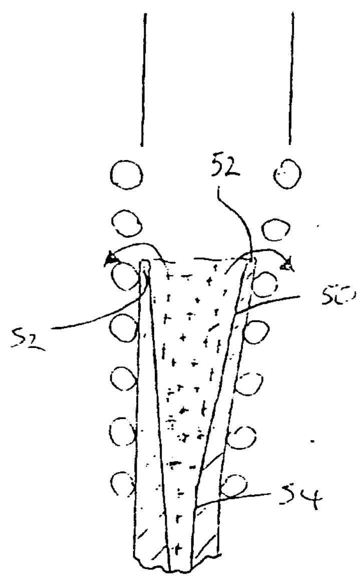


Fig 3

EP 0 903 192 A1

Printed by Jouve, 75001 PARIS (FR)

Description

[0001] This invention concerns improvements in and relating to casting, particularly, but not exclusively to methods and apparatus for manipulating strand thickness by a sequential rolling process, including the location of such changes and / or timing of such changes, for instance when ending a casting cycle.

[0002] There exists a variety of continuous casting processes in which a strand exits a mould and then enters a series of rolling processes. In general, the molten material partially solidifies in the mould to form a relatively thin skin with a still molten core. The molten core is still present when the strand leaves the bottom of the mould. It is preferred to employ a liquid core reduction stage in the initial set of rollers and / or soft reduction stage in the latter sets of rollers to reduce the strand thickness.

[0003] Liquid core reduction allows a slab to be formed of a suitable size for subsequent rolling whilst allowing a meniscus with a larger surface area than would otherwise be possible in the mould. The liquid core reduction stage involves a series of rollers with decreasing spacing, which, as a consequence, reduce the separation between the solidified skins and squeeze the liquid core out. In the prior art the position of this liquid core reduction stage along the strand pass line is fixed.

[0004] At start up of a casting line, it is necessary to introduce a dummy strand of sufficient dimensions to block the lower part of the mould during initial molten material introduction. At the end of the casting stage it is necessary to remove and handle a slab larger than the desired thickness for the rolling stage, but which contains a molten core which cannot be squeezed out merely by progress through a liquid core reduction stage as this would push the molten material out over the top of the end of the strand.

[0005] Providing the desired size of slab for the rolling stage, whilst allowing ready introduction of a dummy strand and handling the still molten core of the end of the strand during the end of strand casting are significant problems.

[0006] The present invention seeks to overcome these problems by manipulating the position of rollers in the initial rolling stage of a sequential rolling process.

[0007] Soft reduction is used to improve internal quality and properties of the cast product. An important criteria, particularly affecting internal quality of high carbon steels (used for example in off shore, heavy plate, line pipe and other constructional steels), is the extent of central segregation and porosity. High segregation results in nonuniform properties across the thickness of the finished product which may be detrimental to the weldability and resistance to hydrogen induced cracking (HIC). Segregation arises during the final stages of solidification. As the steel solidifies, the volume change due to phase transformation generates voids within the strand. The reduced pressure within the voids creates a liquid flow or suction of liquid into the voids. On cooling, the liquid steel may become enriched with alloying elements such as carbon, manganese, phosphorous, sulphur and the like. It is this enriched solution that fills the voids generated by the shrinkage producing an undesirable segregated structure. Soft reduction seeks to provide a solidification bridge or barrier which restricts liquid flow and so the voids cannot be re-filled.

[0008] In the prior art the position of soft reduction along the strand pass line is fixed. Variations in a number of factors, including the material being cast and cooling rates for the strand, effect the appropriate position for optimum soft reduction along the strand pass line. As the location of application of soft reduction is fixed in the prior art, however, such variations lead to the inappropriate location of soft reduction application. The benefits thereof are thus lost and in some cases great harm is done.

[0009] Thus, the present invention additionally seeks to overcome these problems with the positioning of soft reduction, and this fully addresses the problems associated with central segregation and porosity by manipulating the position of the rollers in the final (solidification) rolling stage of a sequential rolling process.

[0010] According to a first aspect of the invention there is provided a method of casting, the method involving a moulding stage for forming a partially solidified strand with a molten core, the partially solidified strand passing to a roller stage on leaving the moulding stage, the method comprising, at least during a portion of a casting cycle :-

providing a first portion of the rolling stage with a reducing separation between rollers, thereby defining a volume occupied by the strand in that portion;
changing the volume of the strand between the rollers in that portion by changing the position of one or more rollers; and
providing a further portion of the rolling stage with a reducing separation between rollers.

[0011] The volume of the strand between the rollers in that portion may be increased. Such a method may be used in liquid core reduction to lower the level of the meniscus with in the solidifying strand. Such a method may be used in dynamic soft reduction to move the location of the soft reduction zone away from the moulding stage / along the direction of travel of the strand.

[0012] The volume of the strand between the rollers in that portion may be decreased. Such a method may be used in liquid core reduction to increase the level of the meniscus within the moulding stage. Such a method may be used

in dynamic soft reduction to move the location of the soft reduction zone towards the moulding stage / against the direction of travel of the strand. The further portion in such a case is provided closer to the moulding stage than the first portion.

[0013] The further portion of the rolling stage may be a different portion of the rolling stage to the first portion and/ or the first portion subsequent to its change in volume.

[0014] According to a second aspect of the invention we provide a method of casting, the method involving a moulding stage for forming a partially solidified strand with a molten core, the partially solidified strand passing to a roller stage on leaving the moulding stage, the method comprising, at least during a portion of a casting cycle :-

providing a first portion of the rolling stage with a reducing separation between rollers, thereby defining a volume occupied by the strand in that portion;
increasing the volume of the strand between the rollers in that portion by changing the position of one or more rollers; and
providing a further portion of the rolling stage with a reducing separation between rollers.

[0015] Preferably the increase in volume is provided by increasing the separation of one or more rollers on one side of the strand from one or more rollers on the other side of the strand. Preferably all of the rollers are increased to a predetermined equivalent separation. Preferably the separation conforms to the equivalent dimension of the mould outlet and / or the initial rolling stage outlet.

[0016] Preferably the further portion of the rolling stage with a reduced separation is a different portion to the first portion / increased volume portion and is provided further, in the direction of travel of the strand, than the first portion / increased volume portion.

[0017] The further portion of the rolling stage may be defined with separations between rollers equivalent to those provided in the initial reduced separation portion. Preferably the separation of the initial rollers of this portion are configured to the adjoining rollers of the increased volume portion. Preferably the last rollers on this reduced portion configured to the separation of adjoining rollers of subsequent portions. Preferably substantially parallel rollers are provided in subsequent portions of the rolling stage.

[0018] Preferably the method further comprises decreasing the volume of the strand between the rollers in the further portion of the rolling stage with a reduced separation between rollers. Most preferably it still further provides, providing a yet further portion of the rolling stage with a reduced separation between rollers. The method may still further provide increasing the volume of the strand between still further portions of the rolling stage and/or providing still further portions of the rolling stage with a reduced separation.

[0019] The increase in volume of the strand between rollers and/or the provision of further portions of the rolling stage with a reduced separation may be provided by varying blocks of rollers simultaneously or by varying one or more rollers in a sequential manner. Thus the gradual movement of the increased volume portion and/or reduced separation portion down a line of rollers is envisaged.

[0020] According to a third aspect of the invention we provide a method of casting, the method involving a moulding stage for forming a partially solidified strand with a molten core, the partially solidified strand passing to a roller stage on leaving the moulding stage, the method comprising, at least during a portion of a casting cycle :-

providing a first portion of the rolling stage with a reducing separation between rollers, thereby defining a volume occupied by the strand in that portion;
decreasing the volume of the strand between the rollers in that portion by changing the position of one or more rollers; and
subsequently providing the first portion of the rolling stage with a reducing separation between rollers.

[0021] Preferably the decrease in volume of the strand between the rollers generates an increased volume of material in the moulding stage. The decrease of volume may therefore give a rise in the level of molten material in the moulding stage.

[0022] Preferably the method provides for the advancement of the strand with the rollers in the decreased volume position.

[0023] Preferably the portion with a reducing separation is provided before the level of molten material reaches the outlet of the mould.

[0024] Preferably the reducing separation portion is provided in an equivalent configuration to the initial reduced separation portion, most preferably in the same portion of the rolling stage. Preferably the separation of the initial rollers of this portion are configured to the adjoining rollers of the preceding portion. Preferably the last rollers of this reduced portion configured to the separation of adjoining rollers of the subsequent portion. Preferably substantially parallel rollers are provided in subsequent portions of the rolling stage.

[0025] According to a fourth aspect of the invention we provide a method of casting, the method involving a moulding stage for forming a partially solidified strand with a molten core, the partially solidified strand passing to a roller stage on leaving the moulding stage, the method comprising, at least during a portion of a casting cycle :-

providing a first portion of the rolling stage with a reducing separation between rollers, thereby defining a volume occupied by the strand in that portion;
changing the volume of the strand between the rollers in that portion by changing the position of one or more rollers; and
providing a further portion of the rolling stage with a reducing separation between rollers., the further portion of the rolling stage being closer to the moulding stage than the first portion.

[0026] The invention, including third and fourth aspects of the invention, may also be provided with the following features and / or options.
[0027] The decrease in volume of the strand between the rollers is preferably provided by reducing the separation of one or more rollers relative to one or more rollers on the other side of the strand. Preferably a reduction between opposing pairs of rollers is provided. Preferably all of the rollers are reduced to an equivalent separation. It is preferred that this separation be substantially equivalent to the corresponding dimension of the desired strand product.
[0028] Preferably the provision of a first portion of the rolling stage with a reducing separation between rollers is provided by increasing the separation between one or more rollers in that portion. Preferably the rollers are moved apart to a decreasing degree in the direction of strand travel.
[0029] The decrease in volume of the strand between rollers and/or the provision of further portions of the rolling stage with a reduced separation may be provided by varying blocks of rollers simultaneously or by varying one or more rollers in a sequential manner.
[0030] Preferably the method provides a strand which is of equivalent thickness throughout its length. Preferably the relative positions of rollers in the non-reducing separation portion are maintained constant throughout.
[0031] According to a fifth aspect of the invention we provide a method of casting, the method involving a moulding stage for forming a partially solidified strand with a molten core, the partially solidified strand passing to a roller stage on leaving the moulding stage, the method comprising, at least during a portion of a casting cycle :-

providing a first portion of the rolling stage with a reducing separation between rollers, thereby defining a volume occupied by the strand in that portion;
changing the volume of the strand between the rollers in that portion by changing the position of one or more rollers; and
providing a further portion of the rolling stage with a reducing separation between rollers, the reducing separation portion preferably providing soft reduction, the reducing separation portion position being moved relative to the moulding stage according to casting conditions.

[0032] The first and/or second and/or third and / or fourth and / or fifth aspects of the invention may further include the following possibilities, options and features.
[0033] Preferably the portion of the rolling stage with a reduced separation is initially provided in proximity to the mould outlet, for instance for liquid core reduction.
[0034] Preferably the reduced separation is provided by decreasing the separation between rollers in the direction of strand travel. The reduction in separation may occur in a linear or non-linear manner. The rate of reduction of separation may be reduced at the start and/or end part of the portion compared with the mid part of that portion.
[0035] Preferably pairs of opposing rollers are provided.
[0036] Preferably the rollers on one side of the strand are provided in a line, parallel to the direction of travel of the strand. Preferably the rollers on one side of the strand are inclined relative to the direction of travel of the strand.
[0037] Preferably the change in position is provided by moving one or more rollers on one side of the strand, the rollers on the other side of the strand remain in position. Preferably all the rollers forming the portion of reduced separation are varied to an equivalent separation. The separation may correspond to the corresponding separation of the mould outlet or to the corresponding separation of the desired product.
[0038] Preferably the portion of the rolling stage subsequently provided with a reducing separation is provided with the same configuration as the first reduced separation portion.
[0039] The moulding stage may involve linear or curved mould or a mould incorporating both linear and curved portions. A mould incorporating a funnel portion may be provided.
[0040] The rolling stage or one or more portions thereof may be provided in a linear configuration and/or in a non-linear (eg curved) configuration and/or in a combination of such configurations. It is preferred that a first portion of the rolling stage after the moulding stage be provided in a linear configuration. Preferably this portion is followed by a

bending portion, with most preferably subsequent further linear and / or non-linear portions being provided.

[0041] In an alternative preferred embodiment, the method of the present invention may be used shortly before final solidification, for instance in a final set of rollers of a sequential rolling process in order to reduce strand thickness (a method referred to hereinafter as "soft reduction").

[0042] Soft reduction may be achieved by any of the variations in roller separation and volume described hereinbefore. Preferably soft reduction may be achieved by providing a tapered roller gap or a variable, roller gap in the area of final solidification which serves to compensate for slab shrinkage and alleviate the aforementioned disadvantages. The position of the tapered roller gap and / or its variation may be dynamically controlled.

[0043] Generally speaking, the extent of soft reduction required to compensate for strand shrinkage is dependent upon steel composition and initial strand thickness. It may be typically of the order of 2% of strand thickness. The liquid steel flow between the solidified dendrites is restricted after about 0.8 solid fraction has been reached. The voids or pores do not refill but simply become re-shaped on reduction. Furthermore the rolling loads become significantly greater when the strand becomes solid. Conversely, applying the method of soft reduction before the strand centre has attained some solidification may limit the observed improvement in segregation. Soft reduction is, therefore, more efficient when used over the preferred solidification range of about 0.3 to 0.8 fraction solid.

[0044] The length of the soft reduction zone may, however, be dependent on the rate of soft reduction. If the rate of reduction at each roller or taper (mm/m) is too great, excessive loads and strains may be experienced at the liquid-solid interface leading to internal cracking. The optimum characteristics of the soft reduction zone are preferably determined by or according to the cooling/solidification rate of the strand and strain limits of the steel being cast. Preferably mathematical modelling may be performed to establish a suitable location and / or length of the soft reduction zone. For 0.3 to 0.8 fraction solid, reduction rates of around 0.6 to 1.5 mm/m may be utilised.

[0045] Thus the length and location of the appropriate soft reduction zone at any point in time may be accurately determined with the aid of heat transference solidification calculations, in order to derive optimum benefit from the strand reduction. Preferably, a computer thermal model is used to assess machine layout, secondary cooling and solidification for a range of casting conditions. Added to strain analyses, the process models may be advantageously used to determine optimum soft reduction characteristics, such as length, location, route, etc.

[0046] At different casting conditions (i.e. steel grade, casting speed, section size, etc), the final solidification position and therefore optimum soft reduction zone may vary. The dynamic soft reduction system described hereinafter allows soft reduction to be advantageously variably applied over some or all segments. Preferably the form of the dynamic soft reduction varies with varying conditions and / or with time. Alternatively, soft reduction may be applied as a heavy line taper over the full support length. Both systems provide for effective soft reduction although a dynamic system is preferred to ensure that optimised reduction rates may be consistently applied. Particularly preferably, the benefits of dynamic soft reduction may be optimised by applying dynamic spray control and thermal tracking.

[0047] Cooling (eg spray cooling) may be provided at one or more portions of the rolling stage, for instance in liquid core reduction and / or soft reduction. The level of cooling may be varied over time to control the amount and hence level of the molten core. Spray cooling applied to a part of the strand having a molten core is preferred.

[0048] An important factor in the efficiency of the soft reduction method is the shape of the solidification point across the width of the strand (the sump profile). This is mainly influenced by the position and cooling intensity of the secondary cooling system. An even sump profile or "U-shape" is preferred to ensure that soft reduction is applied in the correct position over most of the slab width.

[0049] If spray cooling is not set correctly (eg too little cooling at the edge of the strand) solidification does not take place at the same time across the width. This may lead to a "V-shape" or a "W-shape" sump leading to uneven fraction solid across the slab width within the soft reduction zone.

[0050] The required withdrawal force may be calculated according to the resistances acting on the strand resisting it moving through the machine. The resistances include friction due to the mould and roller bearings, as well as slab straightening forces, roller eccentricities and misalignment, etc. When soft reduction is used (or even excessive drive roller pressures), significant rolling forces on the strand are created. These forces increase the withdrawal resistance and thus the required torque of the motors within the casting machine. Sufficient drive capability must be made available to allow withdrawal of the strand. Moreover the effect of increased loading due to soft reduction on strand guide segments require that further checks are made to *inter alia* segment frames, drive rollers and non-drive rollers, roller bearings, roller gap settings and packers, segment drive torques and segment drive motor suitability.

[0051] The casting machine thickness position is normally set by equipment units arranged along the ferro-static length of the casting apparatus from the mould, through the top zone, bender and segments. The setting of these units is normally achieved by clamping frames together hydraulically onto thickness packs. To perform liquid core reduction or soft reduction in accordance with the invention, it is desirable to provide the casting apparatus with a means for adjusting the rollers dynamically.

[0052] Thus one advantageous apparatus for liquid core reduction or soft reduction comprises setting packers for adjusting the roller gap. The segments which may be typically used for soft reduction may be calculated from or pre-

determined based upon, the steel grade to be cast and steady state casting speed. The method of the invention therefore further comprises a step in which the roller gaps are adjusted by static clamping onto preset packers. Subsequent segments are set to the new roller gaps. The location may be optimised to the predicted steady state casting conditions.

[0053] However, it is preferred to carry out the method of the invention with an apparatus comprising remotely operable means for adjusting the rollers dynamically, for example hydraulic means or electromechanical means coupled with a dynamic control system. Preferred dynamic control systems for the hydraulic means are, for example, pulse systems using standard valves or servo or high gain proportional valve systems. Each of these may advantageously use a sensor transducer or similar device at each cylinder to dynamically feedback the signal of the strand position. Due to its location, it may be desirable to instal the system in a pull-down cylinder or a separate piggy-back type cylinder (e.g. an air cylinder). A control device (such as a digital controller) may be used and may be linked to a host computer.

[0054] The advantage of the pulse system using standards valves is that it may be adapted to suit new and existing machinery. The servo system on the other hand may use high gain proportional valves which are less demanding than a true servo valve and may be adaptable to existing hydraulic systems (typically in conjunction with filtration means).

[0055] Thus viewed from a sixth aspect the present invention provides a casting apparatus comprising remotely operable means for dynamically or statically adjusting one or more rollers. Preferably the apparatus comprises a position sensor for determining the position of one or more rollers.

[0056] In a preferred embodiment, a hydraulic cylinder is mounted to the equipment frame and arranged with a dynamic control system and digital controllers. As casting commences, the strand may be tracked with conditions set by a process control computer and set points down-loaded for optimum roller gap setting to the digital controllers that control the movement of fluid through the control valves which in turn move each hydraulic cylinder and set the roller gap. Feedback for the roller gap may be taken from a sensor transducer or the like monitoring the cylinder stroke movement and thus the roller gap.

[0057] Thus in another embodiment, the method of soft reduction is carried out dynamically by including a step in which one or more rollers is adjusted dynamically. For dynamic adjustment, this advantageously involves the automatic adjustment of individual roller gaps to suit the location of final solidification. Dynamic soft reduction may therefore usefully compensate for non-steady state casting conditions. That is to say, during casting, the slab speed varies depending upon conditions and casting practice with the result that the solidification point of liquid metal may move up or down the machine length. It will be appreciated, therefore, that to achieve maximum flexibility for strand roller gap adjustment during casting and to meet the conditions for soft reduction, an apparatus that may respond dynamically and be capable of accurately positioning and setting the roller gap is preferred.

[0058] Thermal tracking provides real time thermal modelling of the cast product with calculations of slab surface temperature, shell thickness and solidification position, etc. To ensure the necessary accuracy, the modelling should have grade dependent thermal and physical properties and spray zone dependent heat transfer coefficients. Such a model may provide calculated slab temperatures and shell thicknesses throughout the casting machine. Numerous real time variables may be inputted into the thermal tracking model including steel grade, casting temperatures, section size, casting speed, mould cooling water flow rates and temperature rises, and spray cooling water flow rates. Thermal tracking model results may be used to provide inputs into the dynamic liquid core reduction and soft reduction control systems to ensure that optimum strand thickness reduction rates and positions are correctly applied in relation to calculated solidification position.

[0059] In accordance with the sixth aspect of the invention, liquid core reduction and soft reduction may be performed dynamically in new casting machines or by retro-fitting appropriate means to existing machines. The benefits of the apparatus of the invention are that liquid core reduction allows thinner sections to pass to the rolling mill therefore less power is required during rolling. Typically, liquid core reduction takes place in the top zone and bender segment. Soft reduction gives enhanced quality off the casting machine for certain grades of material. The soft reduction stage typically takes place downstream of the top zone and bender system in segments 1 to 5 and segments 6 to 7. Reduction over each unit will typically be 2 millimetres.

[0060] An explanation of the invention and various embodiments thereof will now be described, by way of example only, and with reference to the accompanying Figures, in which:-

Figure 1 illustrates a liquid core reduction stage in continuous casting;
Figure 2 illustrates a start up procedure for continuous casting;
Figure 3 illustrates a potential problem with liquid core reduction for the end of a casting strand;
Figure 4 illustrates a first embodiment of the invention for handling the end of a casting strand;
Figure 5 illustrates a second embodiment of the invention for handling the end of a casting strand;
Figure 6 illustrates a typical casting machine suitable for employing the present invention;
Figure 7 illustrates a schematic representation of dimensions and tolerances in a method of the invention in which liquid core reduction precedes soft reduction;
Figure 8a illustrates a typical segment for use in the method of the invention in end on view;

Figure 8b illustrates the segment of Figure 8a in side view;
Figure 9 illustrates a schematic representation of the soft reduction method of a preferred embodiment of the invention;
Figure 10 illustrates a further example of thermal modelling which may be used to highlight the solid fraction positions and proposed location of a soft reduction zone;
Figure 11 illustrates roller gap configurations for soft reduction;
Figure 12 illustrates a preferred embodiment of the apparatus of the invention comprising means for setting a roller gap;
Figures 13a and 13b illustrate entry and exit hydraulic cylinders in end and side view respectively in one form;
Figures 14a and 14b illustrate entry and exit hydraulic cylinders in side view; and
Figure 15 illustrate dynamic liquid core reduction with dynamic soft reduction and static liquid core reduction with dynamic soft reduction.

[0061] Continuous casting of metal typically involves the introduction into a mould 3 of molten material 5, the molten material partially solidifying therein to form a strand 6 comprising a solidified thin skin 7 and a molten core 9.

[0062] To minimise fluctuations in meniscus level 11 in the mould, with consequential improvements in product quality, it is desirable to keep turbulence and other fluctuations to a minimum. It has been found that this consideration is at its best when as large a surface area for the meniscus is as is possible provided.

[0063] To minimise the cost of the subsequent rolling equipment stages 13, however, and also to provide products of the desired thickness, it is desirable to produce slabs of a considerably lower cross sectional area than is desirable for the meniscus area. Thus the fully solidified strand is thinner than the strand leaving the mould by virtue of active compression. This can be achieved through the use of one or both of liquid core reduction and soft reduction stages. Liquid core reduction is frequently employed following the exit of the strand 6 from the mould 3 when the strand has a significant liquid core. Soft reduction is generally carried out at a later stage when cooling has significantly reduced the level of liquid in the strand. The reasons and benefits for these stages are discussed elsewhere in this document.

[0064] In the context of liquid core reduction, as illustrated in detail in Figure 1, the molten material 5 introduced into the mould 3 forms a skin 7 of increasing thickness as the temperature drops for the skin and solidification occurs. However, by the time the strand 6 exits the mould 3 it still possesses a sizeable liquid core 9.

[0065] Reduction of the strand 6 towards a more desirable thickness X can be achieved in the initial rolling stage 13 using liquid core reduction by pushing one or both of the skins 7 towards the other. Thus, pairs of cylindrical rollers 15 are provided with one set provided in a straight line, along the pass line, and with the other set tapering towards the first so as to gradually decrease the separation distance. In this way the opposing solidified skins 7 are brought together and the liquid core 9 is squeezed out. In general this squeezing process leads to a flow of material upwards within the core. A 90mm gap on exiting the mould may well be reduced to a 70mm strand in such a stage.

[0066] During strand casting start up it is necessary to introduce a dummy, solid strand 20 into the bottom of the mould to form a plug whilst the molten material is initially introduced. A start up scheme for such a continuous casting mould is illustrated in Figure 2. The profile of the strand and the accompanying rollers are illustrated in twelve sequential representations, numbered 1 to 12.

[0067] In representation 1, the liquid core reduction (LCR) unit 22, bender stage 24 and rolling stages are all opened to the width of strand corresponding to the mould outlet 26. To plug the mould a dummy strand is inserted with the drive rollers 28 being sequentially moved into grip the thin main length 30 and drive the dummy bar upwards. The dummy bar has an enlarged head portion 32 to block the mould and thinner subsequent portion 30 corresponding to the desired eventual slab thickness.

[0068] Once blocked, representation 2, casting can be started by introducing molten material 34 into the mould 36. As the molten material freezes to the dummy bar head and the initial skin for the strand forms in the mould, the strand drives 28 can be started and the strand withdrawn from the mould 36.

[0069] Initially the LCR unit and bender rollers are set at a fully open separation to accommodate the dummy bar and the cast strand attached to it, representation 3. After sufficient cast strand 40 has passed through the LCR unit, the LCR unit rollers can be reduced in separation to give the desired squeezing effect to reduce the strand 40 down to the desired thickness, representation 4. A tapered stage is thus provided.

[0070] The passage of the dummy bar and subsequent cast strand 40 down through the various stages with the rollers being reduced in separation to conform to the reduced strand thickness is then pursued, representations 5 to 11.

[0071] Eventually the dummy bar 20 exits the rolling stages and a steady state is reached in which molten material is introduced into the mould, is reduced in thickness through the LCR unit and is then rolled in its reduced format in the subsequent bender and other stages.

[0072] A significant problem is encountered when the pouring of molten material into the mould finishes at the end of a casting run. With no further in flow of molten material the level of molten material in the mould drops and will eventually result in a solidified skin and molten core leaving the mould outlet and entering the LCR unit. If the LCR unit

and subsequent stages are maintained with the squeeze effect down to the desired slab thickness then problems occur. As illustrated in Figure 3 if this squeeze is implemented then still molten material 50 from the core flows up from the squeeze stage and spills over the ends 52 of the solidified strand 54 with consequential problems. Because of this it is necessary to allow the passage through the subsequent rolling stages of a large end portion corresponding in dimension to the mould exit, with the rollers having to be separated throughout to accommodate the passage of this thicker material.

[0073] The present invention, amongst other things, aims to solve this problem and increase the effective length of the useable product obtained.

[0074] In the shut down scheme illustrated schematically in Figure 4, a series of sequential representations, numbers 13 to 25 are provided representing various stages in the shut down procedure.

[0075] In representation 13, the casting process is in a steady state with molten material 60 being introduced to the mould 62, withdrawn through LCR unit 64 to reduce its thickness and processed in subsequent benders and other stages.

[0076] Following the stoppage of material being fed to the mould, representation 14, the level 66 in the mould starts to drop, representation 15.

[0077] To accommodate the still molten core, whilst achieving a reduction in the slab thickness the rollers in the LCR unit 64 are opened to a width corresponding to that of the mould outlet, representation 16. This increase in volume 68 of the LCR unit results in a depression in the level of still molten core so leading to a crater 70 in the top of the strand. By promptly also opening the gap between the rollers in the bending stage 72 to a tapered configuration this volume can be further increased and the crater depth increased, representation 17.

[0078] Progress of the strand through this revised roller configuration leads to liquid core reduction in the bender stage with a consequential up flow of molten material and reduction in the crater depth 74 at the end of the strand, representation 18.

[0079] Before the molten core reaches the top level of the strand, however, the rollers of the bender stage 72 are opened to the full width and the rollers of the first segment 76 are increased in separation to provide a gradual taper down to the desired slab thickness. Once again, therefore, an increase in volume is provided with a consequential reduction of the level of the molten core relative to the solidified skins, whilst still achieving a reduction of the slab thickness down to the desired level, representation 19.

[0080] Opening the rollers in the previously tapering stage and gradually opening the rollers in the next stage down line to provide a taper continues to have this effect throughout, thereby avoiding overflow of the molten core over the ends of the strand throughout, whilst achieving a reduction in the slab length which has the undesirable wide thickness.

[0081] Eventually the completely solidified strand, with a minimal distance at the full thickness exits the rolling stage, representation 25.

[0082] An alternative regime for handling the same situation is provided in Figure 5. Again a series of sequential representations of the process are provided in representations 26 to 38.

[0083] As before, in representation 26, steady state casting is occurring with a LCR unit thickness reduction stage 80. Upon stopping in flow of molten material, representation 27, the level 82 of molten material in the mould drops, representations 28 and 29.

[0084] In contrast to the previous embodiment, at this point in time the separation of the rollers in the LCR unit 84 is reduced down to that of the desired strand thickness, representation 30, with the net effect that molten core material is forced back up into the mould giving a molten material level rise in the mould. This material can then be used for slab casting with the result that the level in the mould drops once more, representation 31.

[0085] As the meniscus approaches the bottom of the mould the rollers of the LCR unit 80 are opened to their tapered squeezing configuration once more providing an increased volume 86 between the skins and leading to cratering 88 of the strand end. The strand end then passes into the LCR stage and is reduced in thickness down to the desired extent, but without overflow of the molten core as the increased volume is sufficient to accommodate the up flow of molten material, representation 32.

[0086] In this way, the entire strand is converted to the desired thickness and that strand is gradually withdrawn from the process stream, representations 33 to 37.

[0087] When it is desired to commence casting once more the sequence can be repeated by presenting a dummy bar to the rollers, representation 38.

[0088] Both embodiments of the invention described hereinabove, therefore, involve varying the internal volume of the slab so as to ensure that the molten core is always below the end level of the strand. In this way spillage is avoided. The crater in the meniscus will vary, it will not completely disappear.

[0089] The invention, therefore, allows a large meniscus area to be employed in the mould whilst achieving products of the desired, reduced thickness. Furthermore this is achieved whilst minimising loss of material in an undesirable product form at the end of any casting strand procedure.

[0090] Figure 6 illustrates schematically a typical casting machine comprising mould 600 and top zone 601, bender

602 and segment sections 603a and 603b. Section 603a represents segments a to e and section 603b represents segments f to g.

[0091] The adjustment of the segments is normally achieved by clamping frames together, hydraulically, onto thickness packs. In accordance with the invention, dynamic hydraulic means allow the roller gap in these segments to be advantageously adjusted during casting.

[0092] With reference to Figure 6, the casting methods of the invention may use any one of the following combination of steps:

1) parallel strand thickness typically say 150 millimetres in top zone 601 and bender 602 and in support segments a to e and f to g - no thickness reduction is applied.
2) parallel strand thickness 150 millimetres in top zone 601 and bender 602 and soft reduction in segments a to e and f to g - soft reduction without liquid core reduction.
3) liquid core reduction reducing strand thickness by up to 25mm in top zone 601 and / or bender 602 and soft reduction in segments a to e and f to g - liquid core reduction with soft reduction.
4) liquid core reduction by up to 25mm in top zone 601 and bender 602 and parallel strand thickness in the support segments - liquid core reduction without soft reduction (as described above).

[0093] The purpose of liquid core reduction is to reduce the strand thickness (roller gap) from say 150 millimetres to 125 millimetres. This may be achieved by setting the entry dimension of the top zone segment to 150 millimetres and tapering through to the exit bender segment dimension at 125 millimetres. This tapering reduction of the roller gap is performed at a controlled rate by hydraulic cylinders, finally clamping onto hard packs. Throughout the operation, a sensor monitors the position of the cylinder stroke and thus the roller gap position.

[0094] For steps 1 and 2 above in which the parallel strand thickness is 150mm in the top zone and bender, the strand is set to hard packers. In step 3, liquid core reduction is achieved as follows:

i) position strand roller gap to say 150 millimetres (i.e. move hydraulic cylinders from open position of say 150 and stroke);
ii) as the hot strand runs through the top zone and bender, the units are loaded as per the forces in Table 1 below;
iii) when the hot slab has passed through each unit, it is closed at a control rate onto a set packer thickness and pressure is held during casting;
iv) at the end of cast the strand is brought back parallel to 150 millimetres until cleared through the top zone and bender;
v) provision is required to move the entry cylinders independently of the exit cylinders.

[0095] Soft reduction may be achieved in segments a to e (603a and f to g (603b) and in conjunction with or separately to liquid core reduction to control the final solidification of the casting machine.

[0096] The roller gap position control is achieved through hydraulic cylinders. Packers used in the case of an existing damping method are removed and roller gap adjustment is made dynamic.

[0097] Soft reduction may be achieved as follows:

1) outlet roller gap is set at say 150 millimetres or 125 millimetres from bender (depending on whether liquid core reduction has been applied or not);
2) the segment responds to instructions on set points from the host computer,
3) each segment is capable of roller gap positioning at a controlled rate within a stepless range.
4) forces acting on the segment are defined in Table 1,
5) provision is made to move the entry cylinders independently of the exit cylinders.

[0098] A schematic representation of dimensions and tolerances in a method of the invention in which liquid core reduction precedes soft reduction is shown in Figure 7.

[0099] In Figures 8a and 8b, a typical strand segment is illustrated for use in the method and apparatus of the invention. The main valve manifolds 801 are located outside the spray chamber area 802 adjacent to the equipment with hard piping and hoses to a valve block 803 on each hydraulic cylinder 804 in the spray chamber area 802. Adjusting the hydraulics allows the roller gap 806 to be varied.

[0100] Figure 9 illustrates a schematic representation of the progress of a soft reduction method with the roller positions indicated for a soft reduction taper 902 in a soft reduction zone 903 as compared with a rigid line taper 904 which addresses contraction due to cooling only.

[0101] Figure 10 shows examples of thermal modelling and calculation of fraction solids. The upper results shows the increase in shell thickness for fraction solids ranging from 0.0 (liquidus line) through to 1.0 (solidus line). The lower

result shows the increase in fraction solid at the centre of the slab versus distance from meniscus. This shows that the optimum soft reduction position of typically 0.3 to 0.8fs occurs at say 8.4 to 10 metres from the meniscus. This is within the third (c) and fourth (d) curved support segments.

[0102] Based on the above mentioned calculations the appropriate location under steady state can be determined and based on suitable monitoring the appropriate locations with process variations can be determined.

[0103] Roller gap configurations for a soft reduction process are under a variety of conditions are shown in the resolutions of Figure 11. The formats 1 to 8 show the final solidification point (apex of the liquid core) at various positions along the machine length. Set points down-loaded from the process control computer tracking systems are sent to the position control digital controllers and to the hydraulic cylinders for roller gap setting according to where this solidification point is determined as occurring. Sensor transducers are used to monitor the roller gap position and provide feedback to the control system.

[0104] A preferred embodiment of the apparatus for setting and / or controlling a roller gap is illustrated in Figure 12. The apparatus comprises a hydraulic cylinder 1301 with a sensor transducer 1302 which are mounted to the equipment frame, together with position control valves 1303 and digital controllers 1304. Power for the hydraulics is taken from the main machine system. As casting commences, the strand is tracked with conditions set by the process control computer 1305 and set points down-loaded for setting the optimum roller gap. This is achieved using position control digital controllers that control the movement of fluid through the control valves which in turn move each hydraulic cylinder and set the roller gap. Feedback for the roller gap is taken from the sensor transducer 302 monitoring the cylinder stroke movement 1306 and thus the roller gap.

[0105] The apparatus is designed to control the setting of roller gaps for the following equipment:

top zone - two exit cylinders to give dynamic liquid core reduction;
bender - two entry and two exit cylinders to give dynamic liquid core reduction;
segments - two entry and two exit cylinders to give dynamic soft reduction.

[0106] Entry and exit hydraulic cylinders are arranged at the corners of each unit as shown (as numeral 1401 in Figure 13a and 13b and as numeral 1501 in 14a and 14b). The top zone roller gap is controlled at the exit side by two hydraulic cylinders and pivots at the entry side where the roller gap is fixed. The bender and segments are controlled at the entry and exit side by two hydraulic cylinders on each side (ie by providing independent roller gap movement and setting).

[0107] As liquid core reduction is removed at the end of the cast, the roller gap in the segments is designed to pivot by movement of the hydraulic cylinders thus minimising the liquid core reduction taper and maximising slab yield. Figure 14b shows the segment roller gap pivot movement in the open position as compared to the tapering position of Figure 14a.

[0108] There are a number of soft reduction and liquid core reduction methods which may be used in accordance with the present invention. Preferred embodiments are illustrated schematically in Figure 15. Thus, parts a and b of Figure 15 illustrate dynamic liquid core reduction with dynamic soft reduction and static liquid core reduction with dynamic soft reduction. Figures c and d illustrate no liquid core reduction and dynamic soft reduction. Figure e illustrates heavy line taper.

[0109] Dynamic liquid core reduction with dynamic soft reduction allows dynamic positioning of all strand containment units below the mould. Set points for roller gaps are automatically controlled to maximise accuracy. The control system includes dynamic spray control and on-line thermal tracking together with an apparatus for roller gap setting.

[0110] Static liquid core reduction with dynamic soft reduction allows static positioning of the top zone and bender by clamping onto preset thickness packers and dynamic positioning of soft reduction for the segments.

[0111] No liquid core reduction with dynamic soft reduction allows dynamic positioning of soft reduction for the segments. This embodiment is appropriate if it is desirable not to have the extra slab thickness flexibility offered by liquid core reduction.

[0112] The most cost effective method of setting the strand roller gap is to include line taper by static clamping onto a preset packer thickness and adjusting these packers between casts if required. This system ensures that some degree of soft reduction (albeit at a reduced rate) is always applied without requiring complex control systems and dynamic movements. Table 2 summarises the various alternatives relating to liquid core reduction and soft reduction giving indications of likely effects on product quality.

Table 2

The effect of Liquid Core Reduction and Soft Reduction					
Base = Base proposal which includes line taper only					
i) Dynamic liquid core reduction with dynamic soft reduction DLCR + DSR					
ii) Static liquid core reduction with dynamic soft reduction SLCR + DSR					
iii) No liquid core reduction but with dynamic soft reduction DSR					
iv) Heavy line taper HLT (Benefit - compared to Base case)					
ITEM	**BASE**	**I DLCR + DSR**	**II SCLR + DSR**	**III DSR**	**IV HLT**
INTERNAL QUALITY	0	***	***	***	**
SURFACE QUALITY	0	X 1	X 1	0	0
SLAB EDGE SHAPE	0	XX	XX	0	0
THICKNESS FLEXIBILITY	0	***	**	*	0
ROLL LOADS	0	XX	XX	X	0
MAINTENANCE	0	XX	XX	X	0
CAPITAL COST	0	XX	XX	X	0

Key:
*** Significant beneficial effect
** Moderate beneficial effect
* Slight beneficial effect
o Base case no effect
x Slight detrimental effect
xx Moderate detrimental effect
1 Potentially reduced quality during liquid core movements

Claims

1. A method of casting, the method involving a moulding stage for forming a partially solidified strand with a molten core, the partially solidified strand passing to a roller stage on leaving the moulding stage, the method comprising, at least during a portion of a casting cycle :-

   providing a first portion of the rolling stage with a reducing separation between rollers, thereby defining a volume occupied by the strand in that portion;
   changing the volume of the strand between the rollers in that portion by changing the position of one or more rollers; and
   providing a further portion of the rolling stage with a reducing separation between rollers.

2. A method according to claim 1 in which the volume of the strand between the rollers in that portion is increased.

3. A method according to claim 1 in which the volume of the strand between the rollers in that portion is decreased.

4. A method according to any of claims 1 to 3 in which the further portion of the rolling stage is a different portion of the rolling stage to the first portion.

5. A method according to any preceding claim in which the rollers on one side of the strand are provided in a line, parallel to the direction of travel of the strand and the rollers on the other side of the strand are inclined relative to the direction of travel of the strand in the volume change portion.

6. A method of casting, the method involving a moulding stage for forming a partially solidified strand with a molten core, the partially solidified strand passing to a roller stage on leaving the moulding stage, the method comprising, at least during a portion of a casting cycle :-

providing a first portion of the rolling stage with a reducing separation between rollers, thereby defining a volume occupied by the strand in that portion;
increasing the volume of the strand between the rollers in that portion by changing the position of one or more rollers; and
providing a further portion of the rolling stage with a reducing separation between rollers.

7. A method according to claim 6 in which the increase in volume is provided by increasing the separation of one or more rollers on one side of the strand from one or more rollers on the other side of the strand.

8. A method according to claim 6 or claim 7 in which the further portion of the rolling stage with a reduced separation is a different portion to the first portion and is provided further, in the direction of travel of the strand, than the first portion.

9. A method according to any of claims 6 to 8 in which the method further comprises decreasing the volume of the strand between the rollers in the further portion of the rolling stage with a reduced separation between rollers.

10. A method of casting, the method involving a moulding stage for forming a partially solidified strand with a molten core, the partially solidified strand passing to a roller stage on leaving the moulding stage, the method comprising, at least during a portion of a casting cycle :-

providing a first portion of the rolling stage with a reducing separation between rollers, thereby defining a volume occupied by the strand in that portion;
decreasing the volume of the strand between the rollers in that portion by changing the position of one or more rollers; and
subsequently providing the first portion of the rolling stage with a reducing separation between rollers.

11. A method according to claim 10 in which the decrease in volume of the strand between the rollers generates an increased volume of material in the moulding stage.

12. A method according to claim 10 or claim 11 in which the portion with a reducing separation is provided before the level of molten material reaches the outlet of the mould.

13. A method of casting, the method involving a moulding stage for forming a partially solidified strand with a molten core, the partially solidified strand passing to a roller stage on leaving the moulding stage, the method comprising, at least during a portion of a casting cycle :-

providing a first portion of the rolling stage with a reducing separation between rollers, thereby defining a volume occupied by the strand in that portion;
changing the volume of the strand between the rollers in that portion by changing the position of one or more rollers; and
providing a further portion of the rolling stage with a reducing separation between rollers, the further portion of the rolling stage being closer to the moulding stage than the first portion.

14. A method of casting, the method involving a moulding stage for forming a partially solidified strand with a molten core, the partially solidified strand passing to a roller stage on leaving the moulding stage, the method comprising, at least during a portion of a casting cycle :-

providing a first portion of the rolling stage with a reducing separation between rollers, thereby defining a volume occupied by the strand in that portion;
changing the volume of the strand between the rollers in that portion by changing the position of one or more rollers; and
providing a further portion of the rolling stage with a reducing separation between rollers, the reducing separation portion preferably providing soft reduction, the reducing separation portion position being moved relative to the moulding stage according to casting conditions.

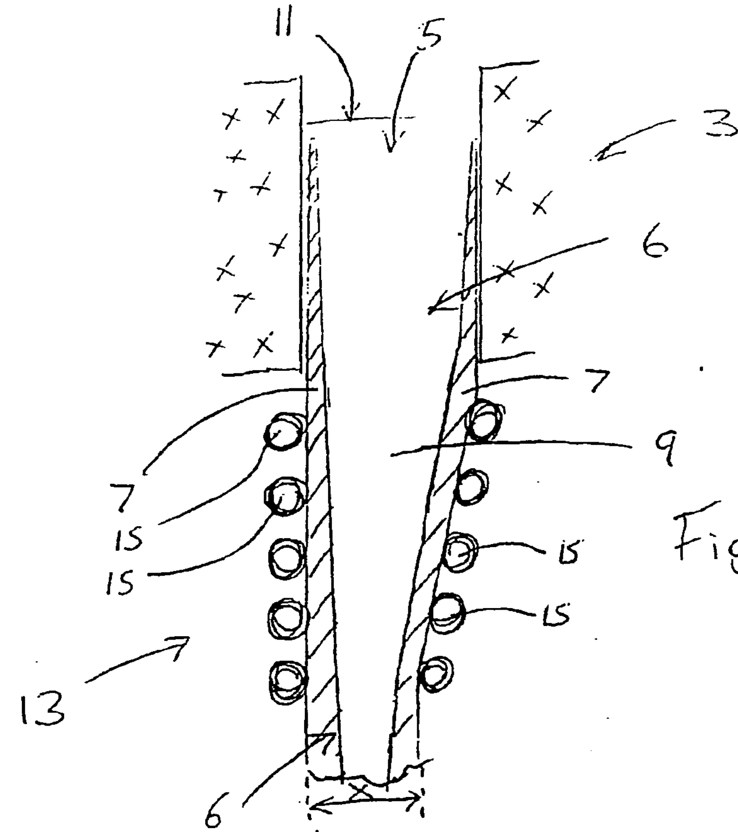


Fig 1

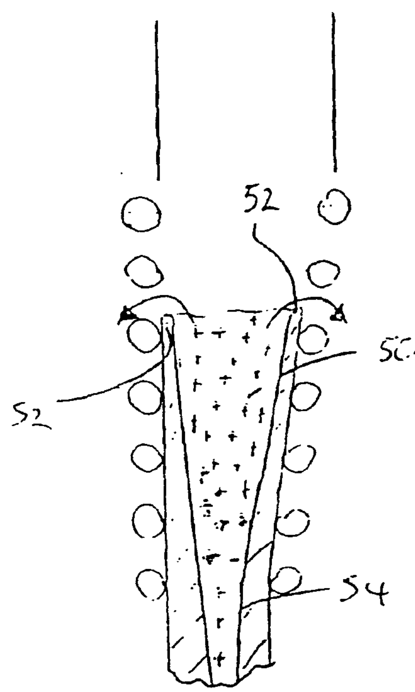


Fig 3

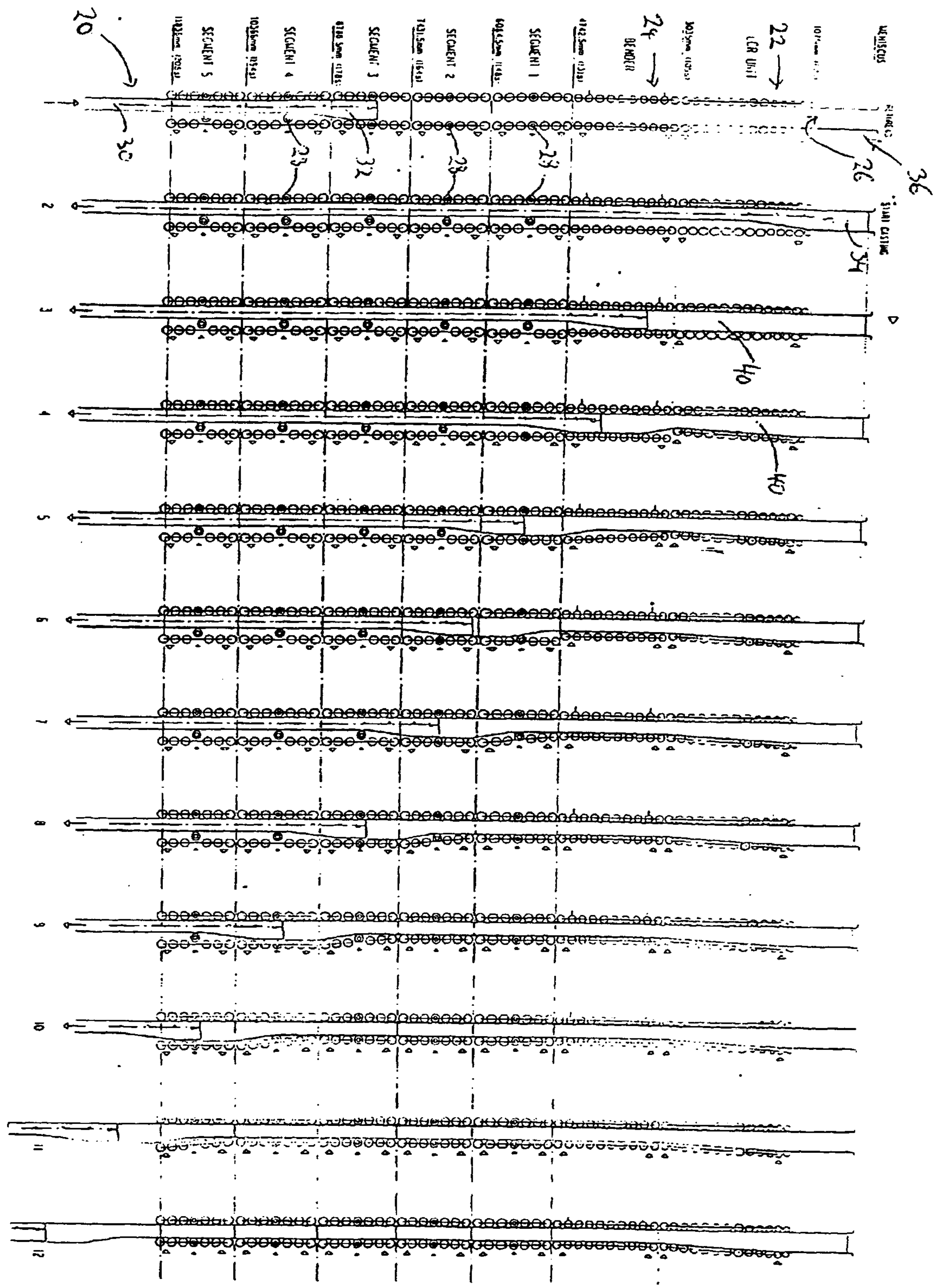


Fig 2

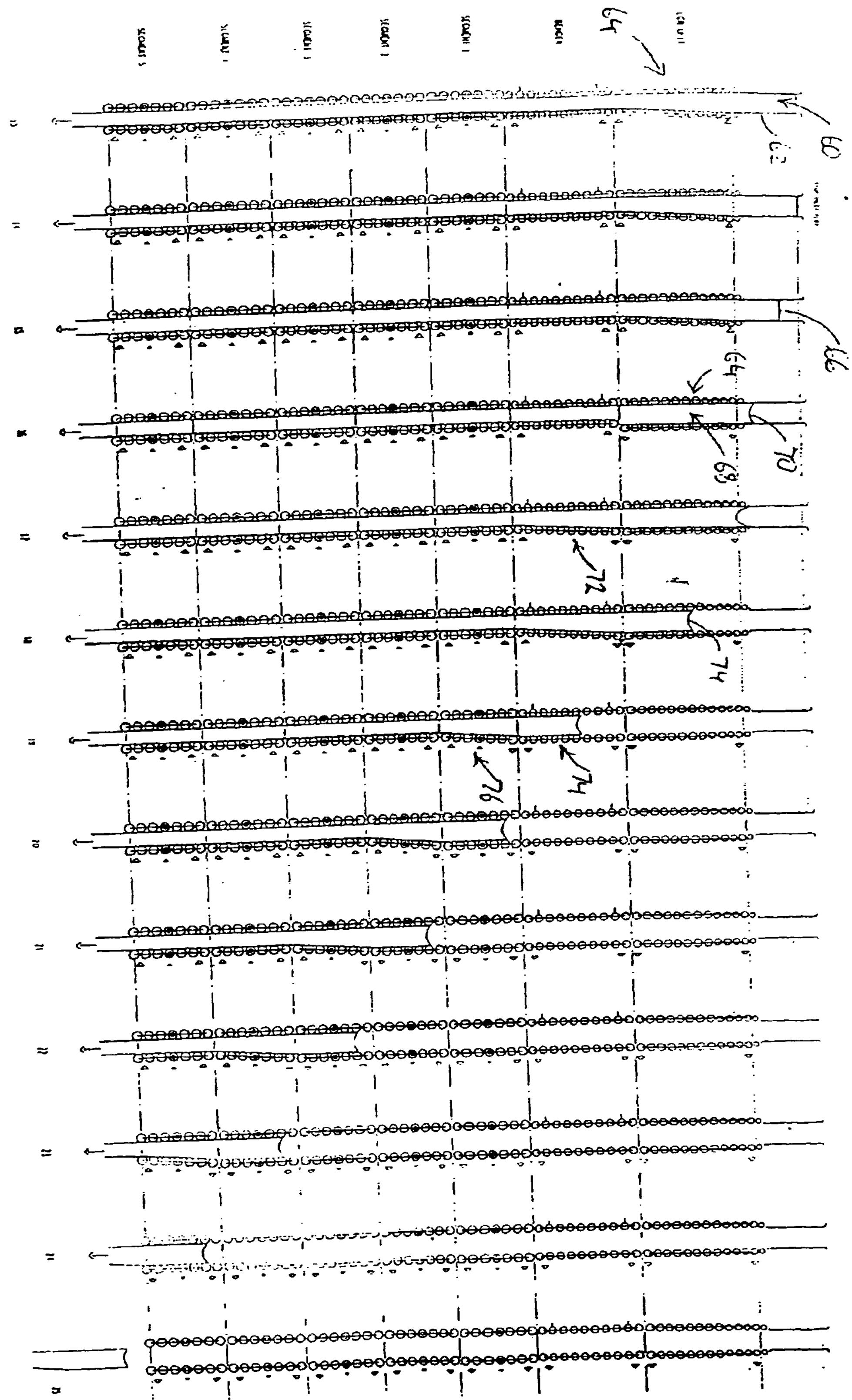


Fig 4

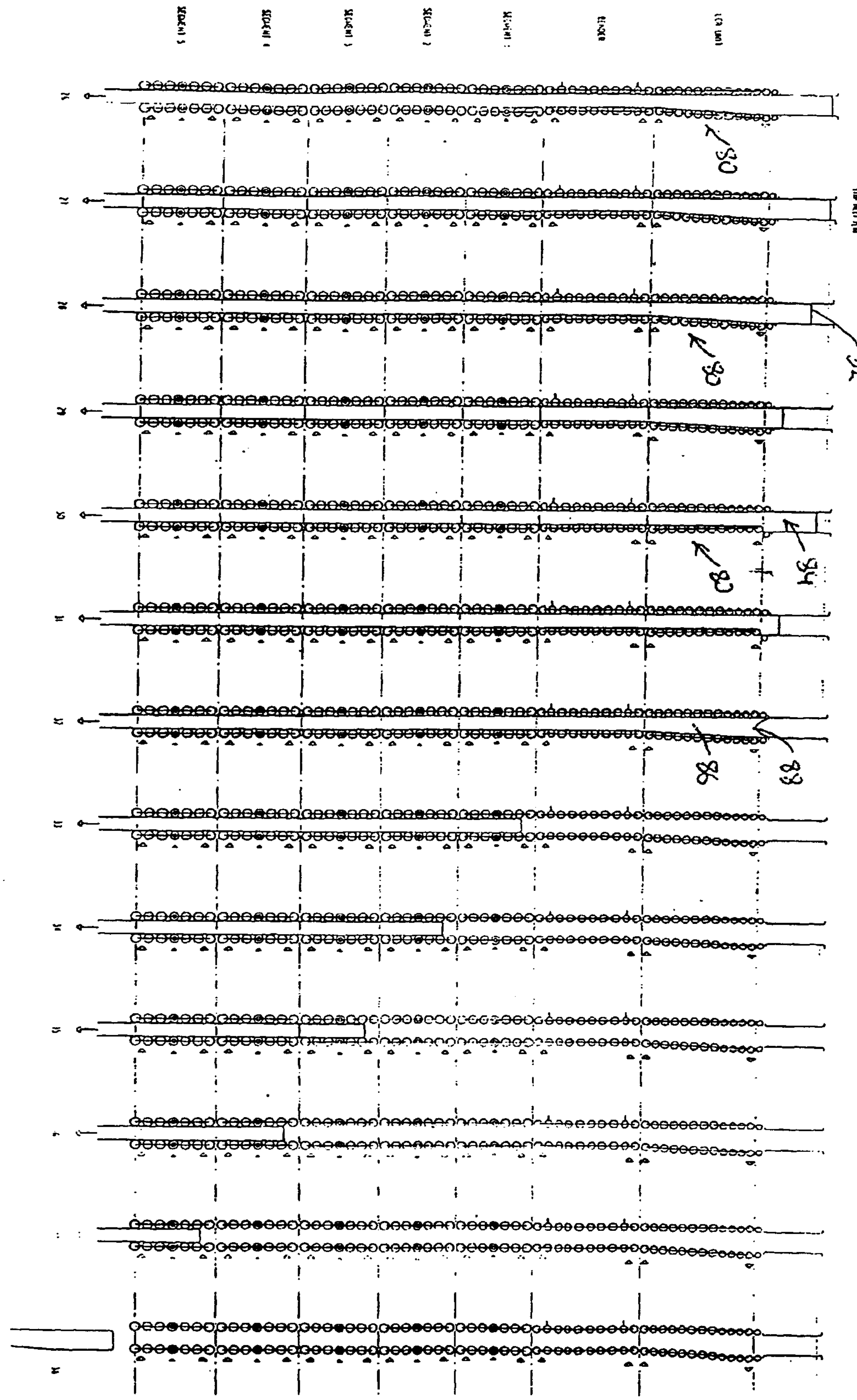


Fig 5

Figure 6

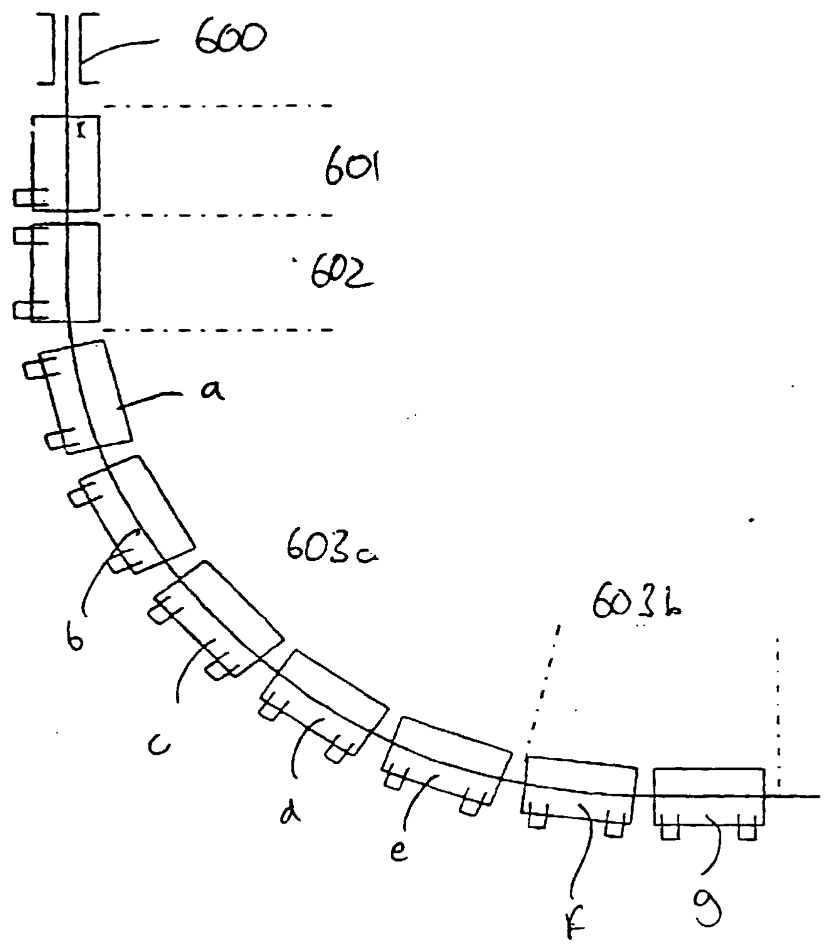


Figure 7

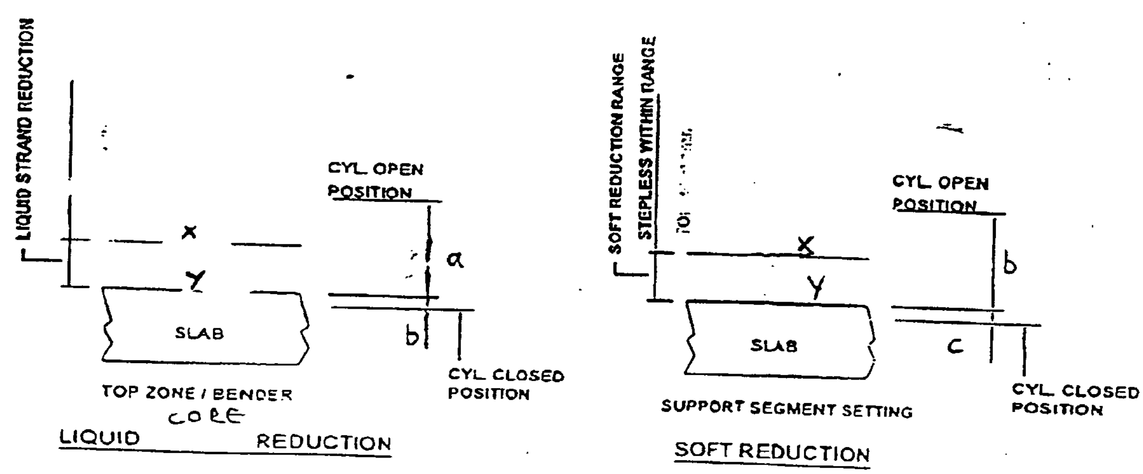

LIQUID STRAND REDUCTION
x
Y
SLAB
CYL. OPEN POSITION
a
b
CYL. CLOSED POSITION
TOP ZONE / BENDER
CORE
LIQUID REDUCTION
SOFT REDUCTION RANGE
STEPLESS WITHIN RANGE
X
Y
SLAB
CYL. OPEN POSITION
b
c
CYL. CLOSED POSITION
SUPPORT SEGMENT SETTING
SOFT REDUCTION

Figure 8a

Fig 8b

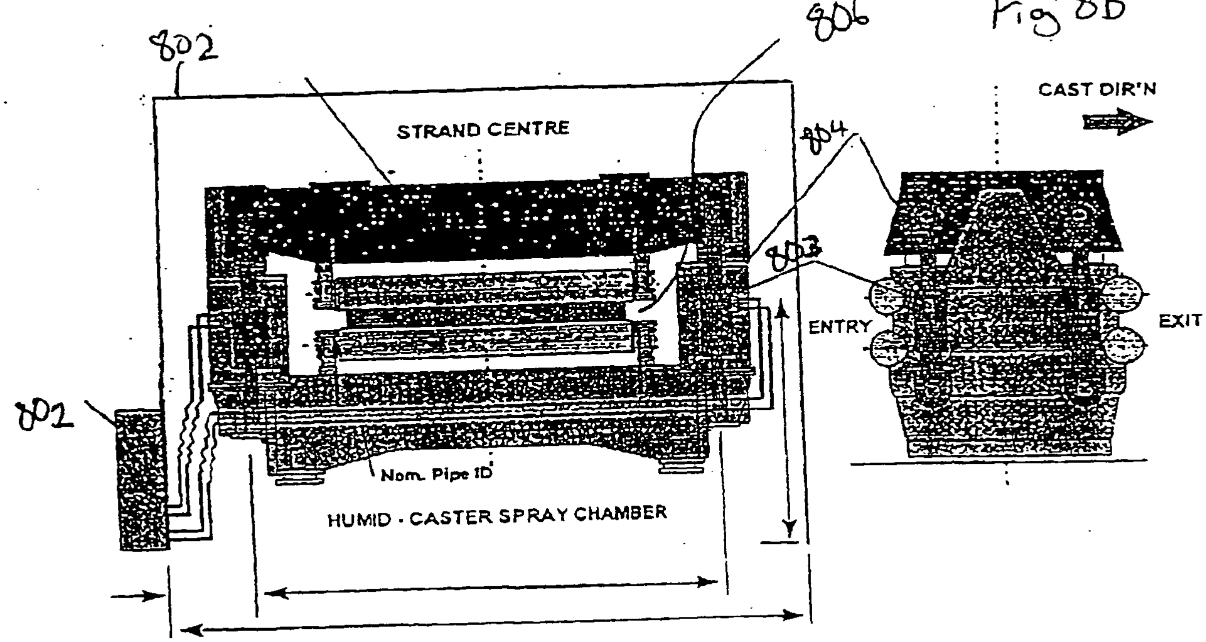


Figure 9

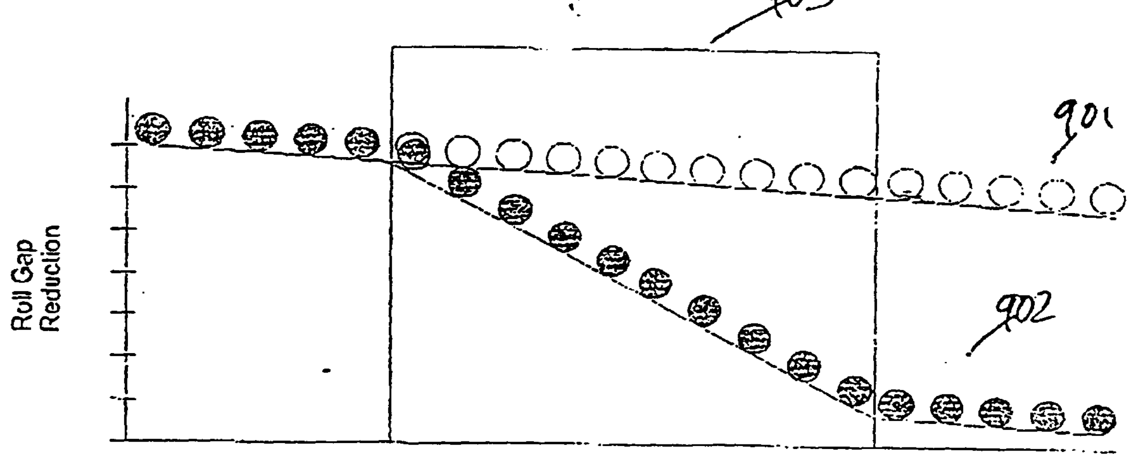
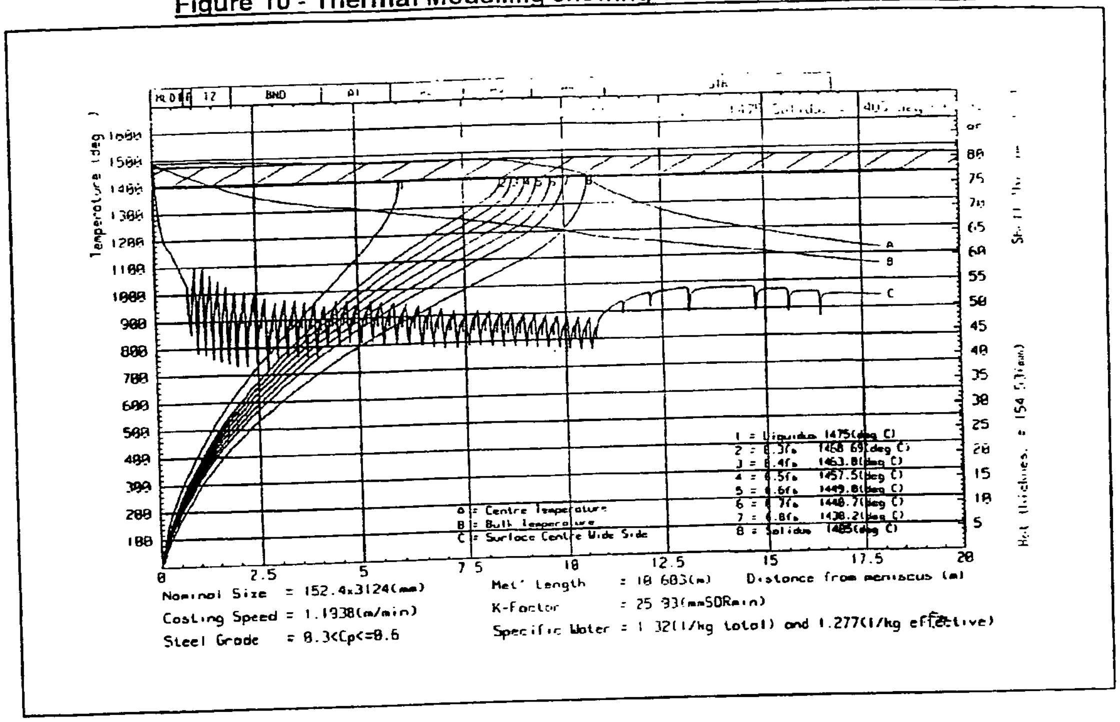


Figure 10 - Thermal Modelling showing Calculated Fraction Solids



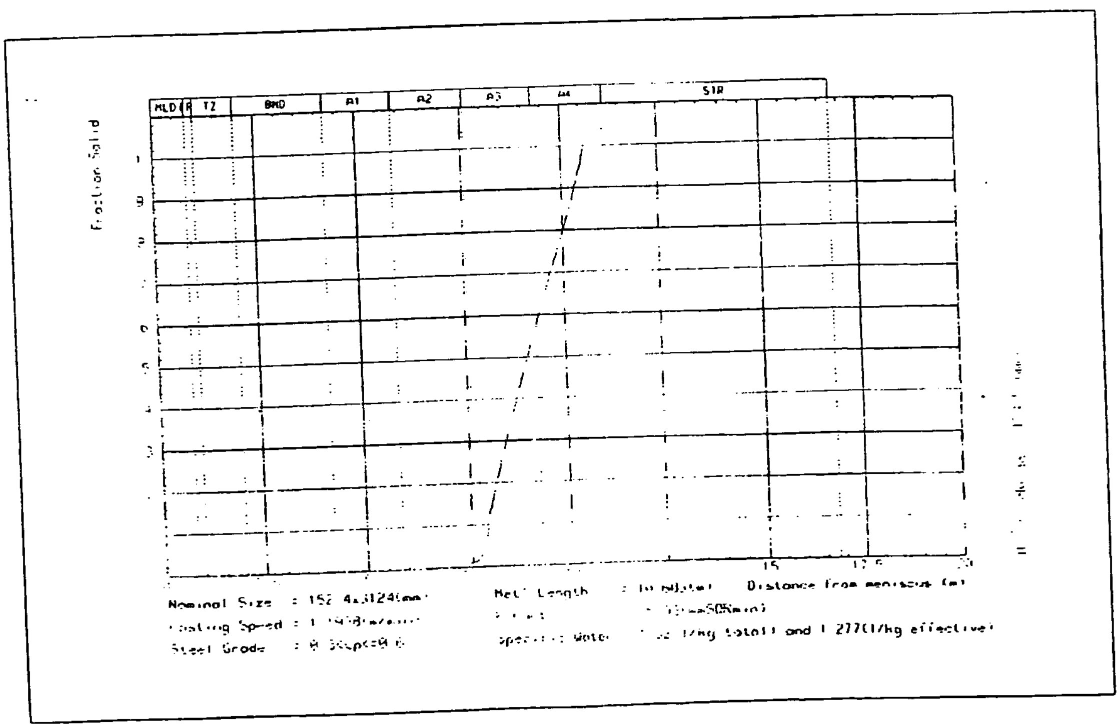


Figure 12

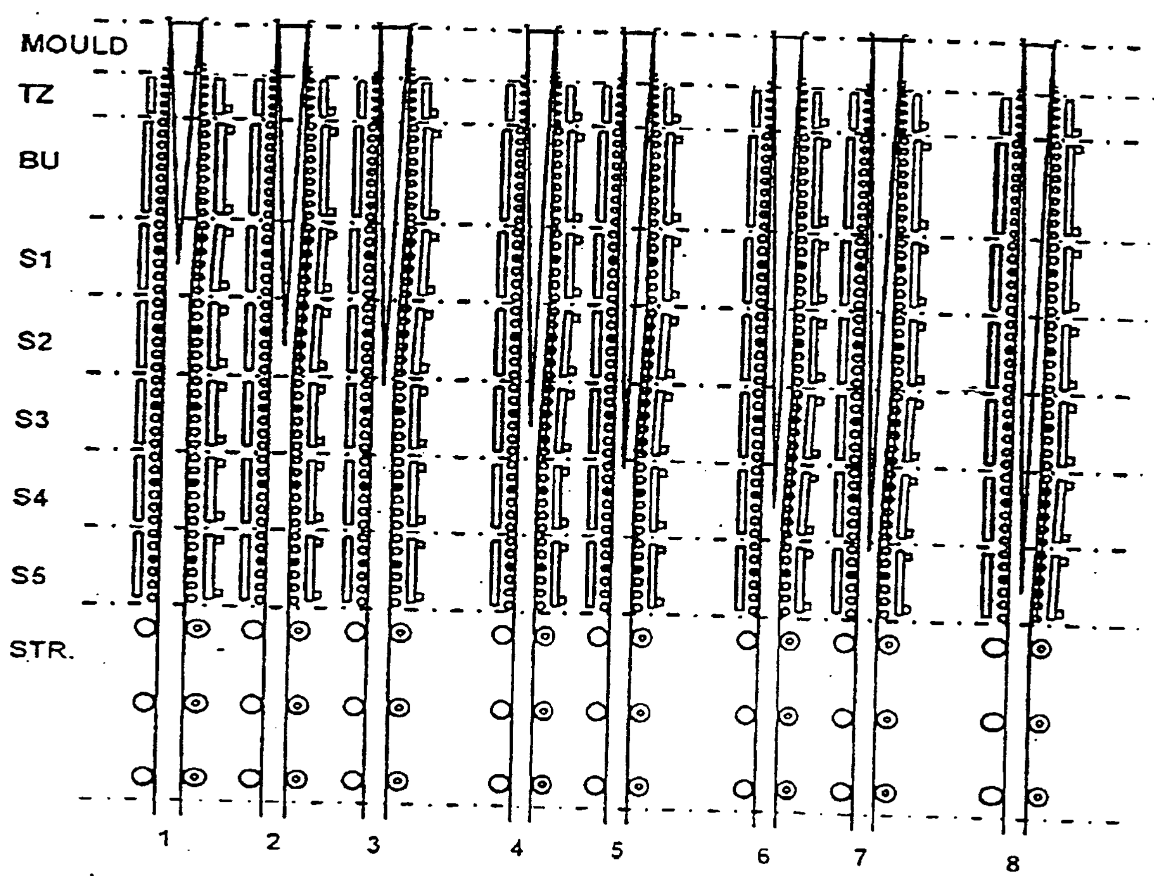


Figure 12

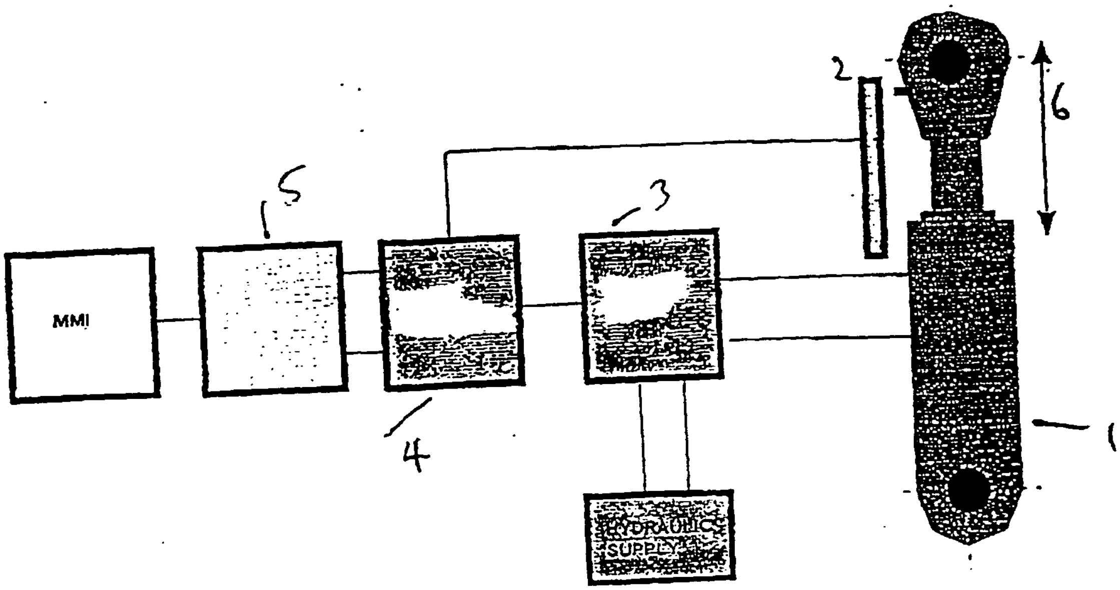


Figure 13a 13b

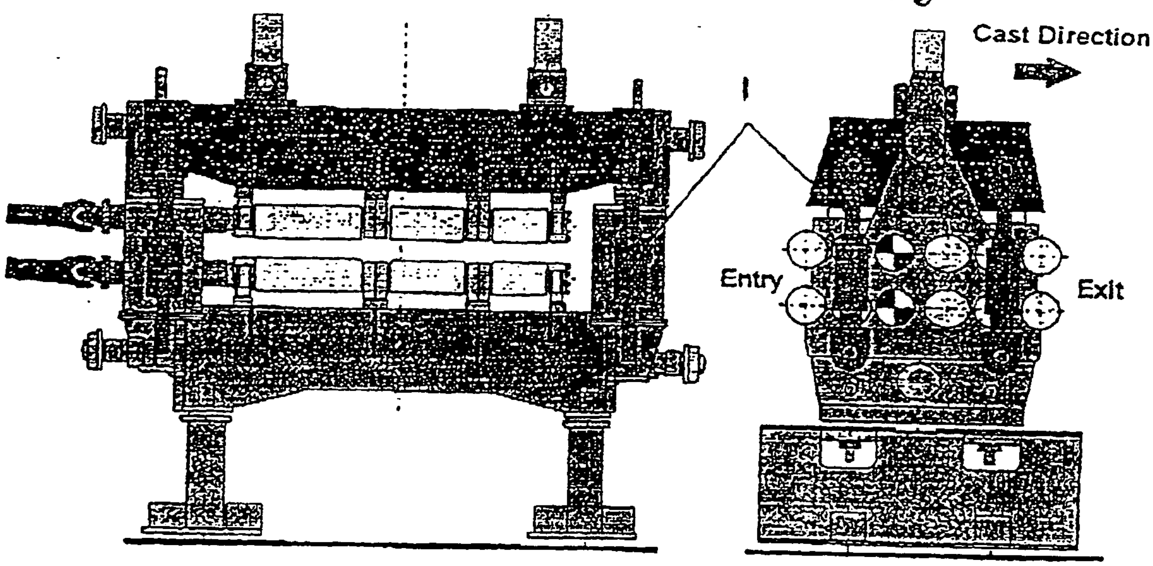


Figure 15

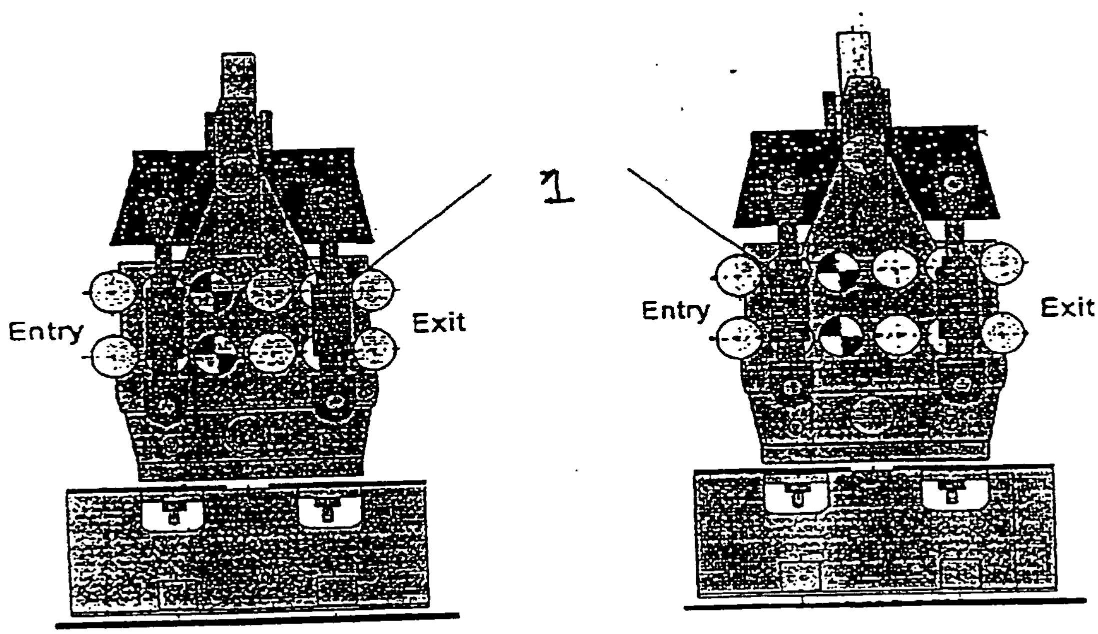
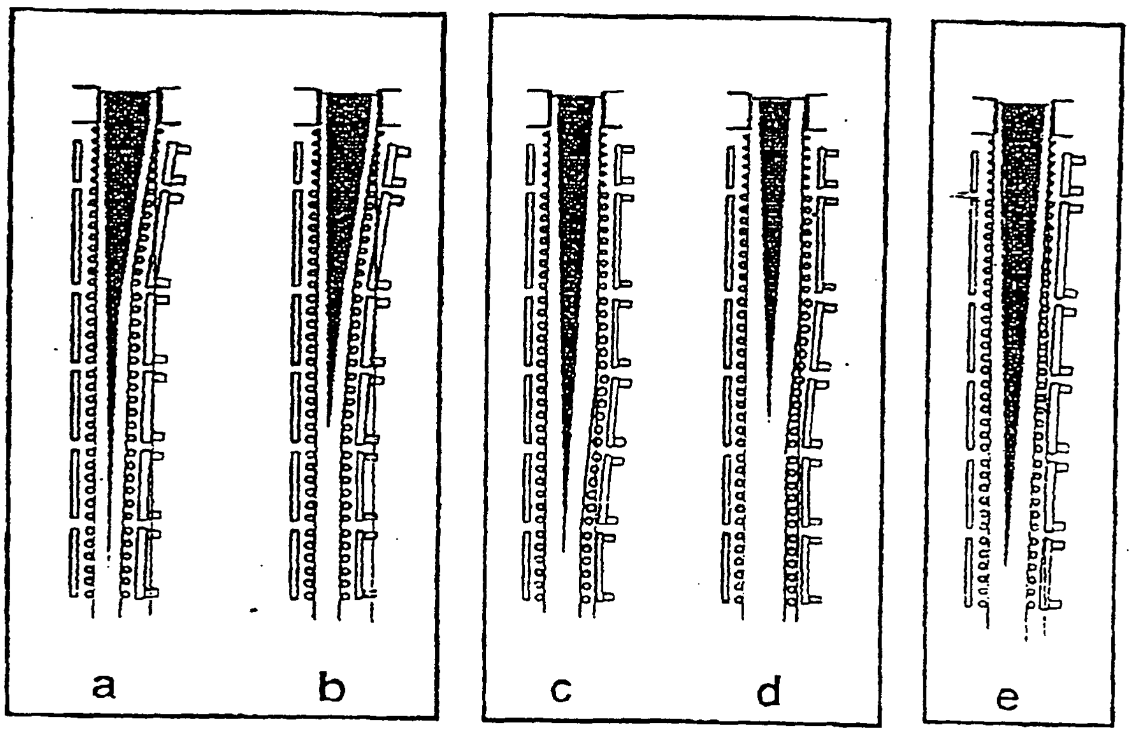


Figure 15.



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 30 7619

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	DE 44 36 328 A (VOEST ALPINE IND ANLAGEN, LINZ, AT) 20 April 1995 * column 1, line 50 - column 2, line 45 * * column 5, line 31 - line 38 * * column 5, line 56 - column 11, line 10 * * figures 1-5 *	1-14	B22D11/12
A	EP 0 730 924 A (SUMITOMO METAL IND., OSAKA, JP) 11 September 1996 * page 3, line 10 - page 4, line 5 * * page 7, line 51 - page 8, line 14 * * figures 1-4 *	1-14	
A	EP 0 611 610 A (VOEST ALPINE IND ANLAGEN, LINZ, AT) 24 August 1994 * page 4, line 1 - line 20 * * figure 1 *	1-14	
A	WO 97 14522 A (SUMITOMO METAL IND ;HANAZAKI KAZUHARU (JP); KOIDE MASAKAZU (JP);) 24 April 1997 * figures 1,7,11 *	6,7	TECHNICAL FIELDS SEARCHED (Int.Cl.6) B22D
A	PATENT ABSTRACTS OF JAPAN vol. 013, no. 441 (M-876), 4 October 1989 & JP 01 170566 A (KAWASAKI STEEL CORP), 5 July 1989 * abstract *	11	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	17 December 1998	Peis, S

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 98 30 7619

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

17-12-1998

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 4436328 A	20-04-1995	AT 401744 B	25-11-1996
		AT 206693 A	15-04-1996
		US 5577548 A	26-11-1996
EP 0730924 A	11-09-1996	JP 8090187 A	09-04-1996
		CN 1131399 A	18-09-1996
		WO 9604086 A	15-02-1996
EP 0611610 A	24-08-1994	AT 398396 B	25-11-1994
		AT 29293 A	15-04-1994
		AU 675099 B	23-01-1997
		AU 5511794 A	18-08-1994
		BR 9400567 A	27-09-1994
		CA 2115489 A	17-08-1994
		CN 1092343 A	21-09-1994
		EP 0853987 A	22-07-1998
		JP 6238410 A	30-08-1994
		MX 9401190 A	31-08-1994
		US 5810069 A	22-09-1998
		ZA 9401032 A	25-08-1994
WO 9714522 A	24-04-1997	EP 0804981 A	05-11-1997

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82